Excited Level Populations in High Current Density Argon Discharges

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(Manuscript received November 2, 1966)

Spontaneous emission intensities of AI and AII in the range 2500 Å to 11,500 Å have been obtained from 2-mm diameter capillaries operated at filling pressures between 0.45 and 5.0 torr and currents up to 10 amperes. Only the AII results at 0.6 torr and 5 amperes are reported

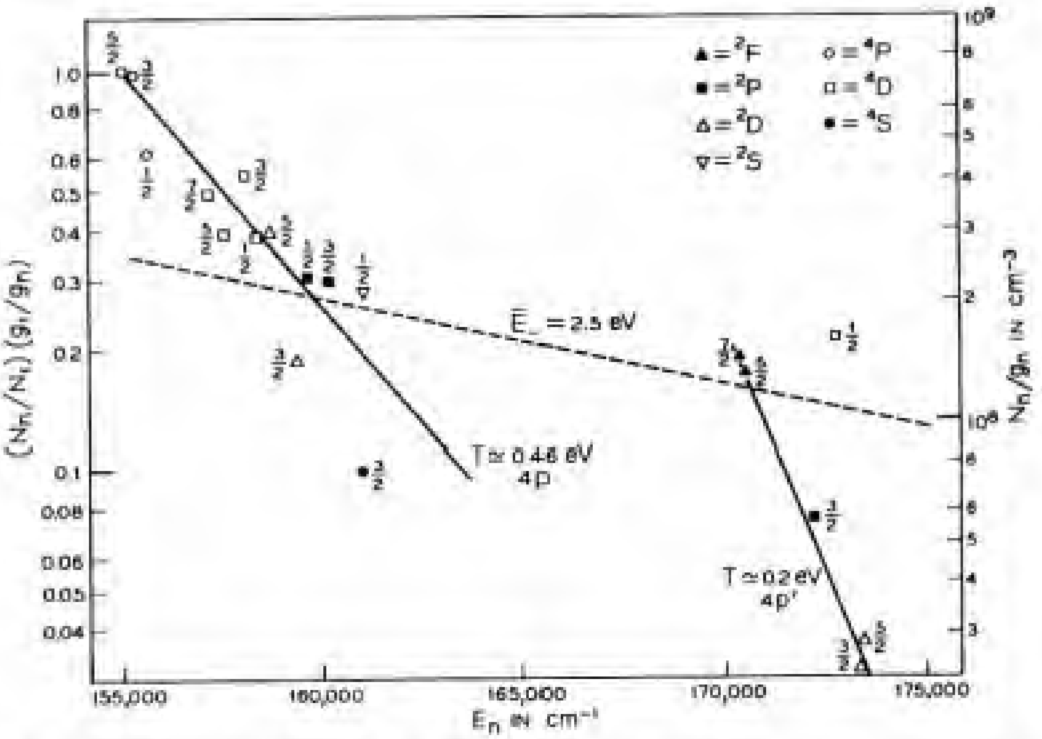

Fig. 1 — Level population in the $4p$ and $4p'$ configurations of AII in a capillary discharge. Capillary diameter = 2 mm, discharge current = 5 amps, filling pressure = 0.6 Torr. The value of electron mean energy $\bar{E}$ was obtained from shielded double probe measurements and the absolute value scale from Ladenburg–Reiche measurements.

here. The spectral sensitivity of the detection system was calibrated with a standard lamp, and the resolution was ≈1 Å. Effects of optical gain and absorption were verified to be negligible for AII.

Relative AII magnetic sublevel populations, N_n/g_n, determined by dividing relative spontaneous emission intensities by measured or estimated A-coefficients[1,2,3,4,5] and by the statistical weight g_n of the emitting level n, are shown in Fig. 1 as functions of excitation energy

E_n above the AII ground state. The results have been normalized to the $4p\,^4P_{5/2}$ population, designated (N_1/g_1), at $E_1 = 155{,}044.07$ cm^{-1}. Hence, the quantity plotted is $(N_n/N_1)(g_1/g_n)$. An approximate absolute value scale of N_n/g_n, obtained from optical absorption measurements,[6] is also shown.* When A-coefficient estimates† existed for several transitions originating from the same level, their self-consistency was checked,‡ and the average value was used.

The $4p$ and $4p'$ populations appear to be grouped along straight lines in the semilogarithmic plot of Fig. 1. Thus, for each of these configurations it is possible to define a "configuration temperature" T (measured in energy units) by the relation

$$(N_n/N_1)(g_1/g_n) \equiv \exp\,[(E_n - E_1)/T].$$

This yields $T \approx 0.45$ and 0.2 eV for the $4p$ and $4p'$ levels, respectively. A line corresponding to $T = 2.5$ eV (the measured value[6] of electron mean energy) has been included for reference.

The existence of an approximately common "temperature", considerably smaller than the prevailing electron "temperature", for all levels within a given configuration (regardless of spin) implies that *intra*-configuration thermal equilibrium is achieved by rearrangement of configurational populations in a time short compared to AII $4p$ and $4p'$ radiative lifetimes, and does not involve charged particle impact.§

Our present belief is that although the excitation energy of AII states is provided by electron impact on the ion, these states can interact rapidly by collisions with the ground and excited states of AI, the final state ion being in the initial AII configuration but not necessarily in the initial level of that configuration. The existence of such collisions might account for part of the large Lorentz broadening of AII line profiles at high current densities.[8] The present experiments yield no information on actual details of these collisions, but there are experimentally documented processes such as formation of molecular ions

* These measurements show that AII $4s$ metastable populations are in approximate Boltzman equilibrium with the AII ground state at the prevailing electron mean energy.

† The lifetime measurements of Ref. 1 and the calculations of Ref. 2, because of their generally excellent consistency, were adopted in preference to earlier estimates whenever such choice was possible.

‡ This check was possible only for the AII $4p \rightarrow 4s$ calculations of Ref. 2 where, with one exception, the self-consistency was better than 30 percent.

§ This latter restriction is required by the AI and AII spontaneous emission radial profiles,[7] provided that AII excited level populations are derived *ab initio* from electron impact on the AII ground state. The fact that "configuration temperatures" are much lower than the electron mean energy independently suggests that electron impact is not responsible for the rearrangement.

(regarded here as a non-stationary intermediate state) which provide a basis for discussing population rearrangement.

If a resonant nature is supposed for the proposed interaction,* then AII leve's are expected to interchange populations rapidly if their excitation energy differences are no larger than the measured 0.1-0.2 eV ion and atom thermal energies.[8,9] The maximum energy differences of 0.1 and 0.2 eV which exist between adjacent levels of the $4p$ and $4p'$ configurations, respectively, imply that the achievement of *intra*-configurational thermal equilibrium is plausible. *Inter*-configuration interaction rates, on the other hand, will be small if the energy gap between them is much larger than $\approx$0.1-0.2 eV (true for the 1.1 eV energy difference between the highest $4p$ and the lowest $4p'$ levels), so that different configurations may very well attain different "temperatures". Also selection rules may reduce or prohibit inter-configuration interactions, core changes, e.g., being difficult to achieve from impact parameter considerations. The existence of an approximately common "temperature" for doublet and quartet $4p$ levels implies that at least some rearrangement cross-sections involving spin change are comparable to those involving no spin change.

From measured discharge parameters[8,10] it can be shown that, if the AI ground state were the sole source of rearrangement collisions, cross-sections $\approx 2 \times 10^{-14}$ cm^2 would provide "thermalization" times shorter than typical $4p$ radiative lifetimes (5×10^{-9} sec). This value is experimentally plausible for resonant collisions between heavy particles,[11] particularly if one of them is in an excited state. Finally, it should be noted that if the above collisions are predominant over radiation, then the determination of cascade contributions to individual levels cannot, in general, be made simply by comparing the total spontaneous emission rates out of and into the level.

Note added in Proof: Where comparison is possible, the absolute level populations of Fig. 1 are in fair agreement with values obtained by Bennett, et al[12] at somewhat lower (pd).

* We do not wish to imply that the suggested collisions must necessarily be treated as a charge-exchange process.

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CW Operation of LSA Oscillator Diodes—44 to 88 GHz

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(Manuscript received November 14, 1966)

Bulk n-GaAs oscillator diodes have been operated on a continuous basis in the LSA (Limited Space-charge Accumulation) mode[1] at frequencies from 44 to 88 GHz. This is the first time a practical solid-state oscillator has operated continuously in this high-frequency range. The reason the LSA diode can produce millimeter wave power at higher frequencies than other solid-state devices such as transistors, tunnel diodes, IMPATT diodes, and Gunn diodes is because it is the first device which is not subject to the "transit-time limitation."

The "transit-time limitation" exists for these other devices because they must be designed so that the time required for a charge carrier to move from the source contact to the drain contact must be shorter than or on the order of one RF cycle. A common principle of all these devices is the bunching of space charge which remains until it drifts into a contact. Since carriers in semiconductors such as silicon, germanium, and gallium arsenide have maximum drift velocities on the order of 10^7 cm/sec, devices for higher frequencies must be designed with proportionally thinner active regions. The power and impedance of such a device both decrease proportionally to the thickness of the active region, so the maximum value of the product of power and impedance decreases as the square of the thickness or as the reciprocal of the square of the frequency, f. The lowest impedance which is practical increases with frequency at microwave frequencies because of skin effect. The